Effect of Die Coating on Friction Behavior of 7075 Aluminum Alloy Sheet in Hot Stamping

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Abstract. The rapid growth of automobile ownership has put tremendous pressure on the environment and energy, so it is particularly important to promote the lightweight of automobiles. Aluminum alloy is an ideal lightweight material with excellent comprehensive performance, which can improve the performance of parts while reducing weight. The application of hot stamping process for heat-treatable aluminum alloy sheets has solved the sever defects like cracking and springback during room temperature, and promoted the application of aluminum alloy. At present, one of the key issues that restricting the promotion of the aluminum alloy hot stamping process is the severe friction problem. At elevated temperatures, the aluminum alloy is easy to adhere to the die surfaces. The material transferred from the aluminum alloy will form bonding points on the die surface, scratch the sheet surface, and cause severe galling. Therefore, this paper takes 7075-T6 aluminum alloy sheets as the object, the friction behavior of boriding treatment, ta-C coating, and WC-a-C:H coating with H13 hot work die steel at elevated temperatures were studied. The results showed that the coatings all showed excellent lubricating effects at 300 °C. Among them, the samples with boriding treatment have the minimum average friction coefficient at 300 °C, and it shows the best anti-adhesion ability. The friction performance of the WC-a-C:H coating at 300 °C is more stable than the others.

Keywords: 7075 aluminium alloy · Hot stamping · Die coating · Friction behaviour

1 Introduction

The application of hot stamping technology and the use of lightweight materials play an important role in the field of automotive lightweight, which provides the possibility for the application of aluminum alloy in the automotive field. The application of hot stamping process for heat-treatable aluminum alloy sheets has successfully solved the problems of cracking and springback during cold forming. However, the high friction coefficient of aluminum alloy during hot stamping process leads to large flow resistance of sheet metal. At the same time, serious adhesion between aluminum alloy and die will occur at elevated temperature, scratching the sheet metal, resulting in roughening or even cracking of the part surface. The poor friction behavior during the forming process

Y. Zhang and M. Ma (Eds.): ICHSU 2022, AHMST 2, pp. 235–242, 2023.
https://doi.org/10.2991/978-94-6463-114-2_32

restricts the further promotion of this technology. Increasing the hardness of the die surface can effectively reduce the wear and friction coefficient, but it has little effect on the adhesion during elevated temperature friction [1]. The use of self-lubricating coating on the die surface is a potential solution to reduce the friction coefficient and the adhesion between the aluminum alloy and the die [2]. Horiuchi et al. [3] prepared three kinds of DLC coatings by CVD method, and conducted friction tests on A5052 aluminum alloy at room temperature and 200 °C. The results showed that DLC coatings can significantly reduce the friction coefficient. Dong et al. [4] took AA6082 as the research object, and carried out high-temperature deep drawing and friction experiments with WC:C die coating prepared by cathodic arc enhanced PVD method. They achieved a pull-down depth of 70 mm under the condition of 20% lubrication at 430 °C, greatly reduced the adhesion phenomenon, and the measured friction coefficient is far lower than the dry friction state. In order to solve the problem that the strength of single-layer coating decreases at high temperature, Dong et al. then studied NC/WC:C [5, 6] and NC/Ni BN [6] two-phase coatings. At the same time, some scholars have proposed the method of adding solid lubricants into the coating and matrix materials [7].

In this paper, 7075-T6 aluminum alloy plate is taken as the research object, and the friction experiment is carried out on the plate elevated temperature friction testing machine. The friction coefficient in the experimental process is obtained, and the lubrication effect of the coating and surface adhesion at different temperatures are compared.

2 Experimental Method

2.1 Materials and Testing Machine

The friction pair materials used in the experiment were H13 steel, and the surface treatments were boriding, ta-C coating and WC-a-C:H coating respectively. 7075 friction strip sample size is 600 × 45 × 1.5 mm. Before the test, remove the oil stain on the surface of the plate with alcohol, and conduct ultrasonic cleaning on the friction head. The chemical composition of hot work die steel H13 and 7075 aluminum alloy plate is shown in Table 1.

Figure 1 shows the equipment used in the friction test. The friction form of the friction pair used in the test device is surface to surface contact. During the test, the sheet moves in one direction, which is more in line with the contact state between the aluminum alloy sheet and the die in the actual hot stamping production. The heating mode adopts tubular heating furnace, which conforms to the heating mode in actual production. The temperature of sheet metal was measured by infrared thermometer in real time during the experiment process.

Table 1. Main chemical composition of H13 steel and 7075 aluminum alloy sheets (wt.%)

Material	Al	Fe	Cr	Cu	V	Mo	Zn	Si	Mn	Mg	C
H13	-	-	5.2	-	1.2	1.5	-	1.1	0.3	-	0.4
7075-T6	-	0.14	0.21	1.64	-	-	5.9	0.03	0.18	3.16	-

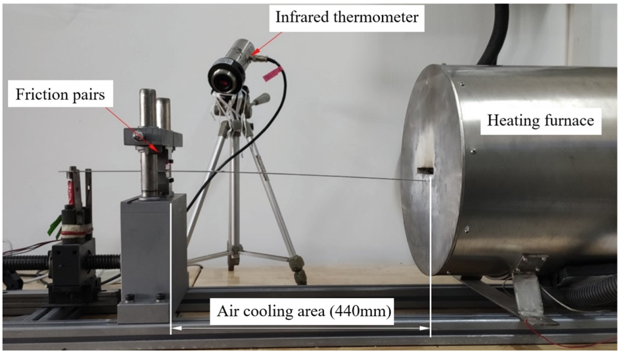

Fig. 1. Friction test device.

Table 2. Experimental parameters for measurement of COF.

Process parameters	Parameter selection
Sheet temperature (°C)	300/350/400/450
Friction pairs temperature	Room temperature
Friction pair surface treatment	Boriding treatment/ta-C coating/WC-a-C:H coating
Sliding speed (mm/s)	75
Normal force (N)	28

2.2 Experimental Methods and Procedures

First, set the heating furnace to 490 °C, after the furnace temperature is stable, put the whole plate into the heating furnace for heating and holding for 15min to complete the solid solution treatment, then take out the plate for air cooling for a predetermined time, then start the servo motor to pull the plates at the set speed to complete the test process, and the infrared sensor continuously collects the temperature changes of the plates during the experiment. Since the normal force is loaded by heavy objects during the experiment, it can be considered that the normal force remains unchangeably during the experiment, so the friction coefficient is $\mu = F/(2Fn)$. After the experiment, the friction coefficient values in the test process were counted to observe the adhesion of the friction pair surface, and the friction pair was selected to be cleaned with alcohol ultrasonic. The viscous substances on the friction pair surface were analyzed by environmental scanning electron microscope and supporting energy dispersive spectrometer. The experimental process parameters are shown in Table 2.

3 Results and Discussion

3.1 Analysis of Friction Behavior Under Different Surface Treatments

It can be seen from the experimental results that the friction coefficient of the boriding friction pair fluctuates in varying degrees during the high-temperature friction process, especially at 350 °C, and the friction coefficient has an upward trend. Compared with other conditions, the friction coefficient at 400 °C and 450 °C fluctuates slightly, but the average friction coefficient is close to 1, which can hardly play the role of lubrication. It is worth mentioning that at 300 °C, the minimum average friction coefficient is 0.647 (Fig. 2).

Figure 3 shows the friction coefficient curve between the friction pair treated with ta-C coating and 7075 aluminum alloy plates. In the whole sliding process, the fluctuation of friction coefficient curve is improved compared with the results under boriding treatment. At 300 °C, the average friction coefficient is 0.71, which has a good lubrication effect. However, at 350 °C and 400 °C, the average friction coefficient is greater than 1, and there is almost no lubrication.

By analyzing the friction results between the friction pair treated with WC-a-C:H coating and the aluminum alloy plates, it can be seen that the friction coefficient fluctuates at 0.5–1 at 300 °C, with a small fluctuation range. Compared with the friction coefficient curve obtained by boriding treatment at the same temperature, the friction coefficient decreases to less than 0.7 after 350mm in this condition. Under the other temperature conditions, the average friction coefficient is 0.8–1.1 and fluctuates violently, which has little effect on the lubrication of sheet metal sliding process (Fig. 4).

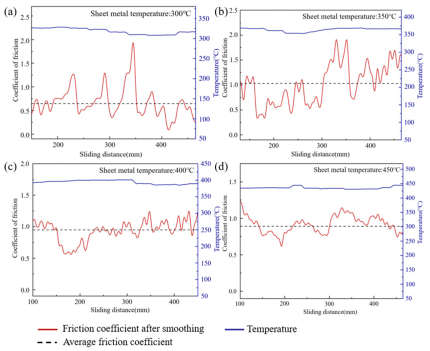

Fig. 2. The COF curves after boriding treatment.

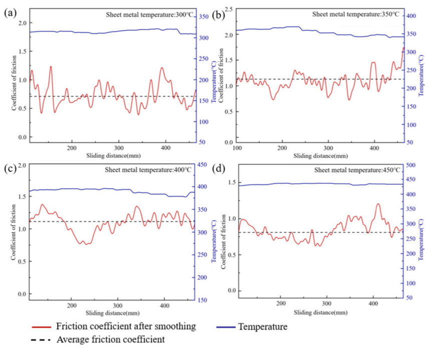

Fig. 3. The COF curves after ta-C coating treatment.

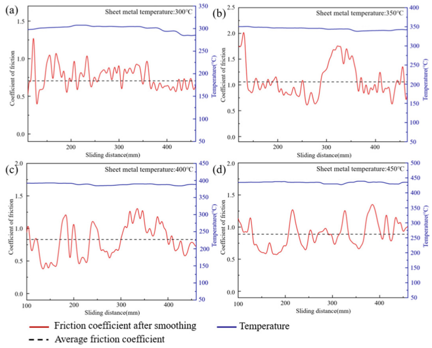

Fig. 4. The COF curves after WC-a-C:H coating treatment.

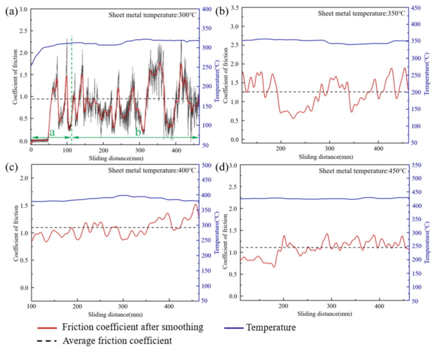

Fig. 5. The COF curves under dry friction condition.

In order to compare the effect of die coating and the friction behavior at different temperatures, the experiments under dry friction conditions were also carried out. As can be seen from the results shown in Fig. 5, the friction coefficient between aluminum alloy sheets and friction pairs is very high at elevated temperature. The average friction coefficient is in the range of 0.906–1.261 with violent fluctuation. At the same time, it also shows that it is very necessary to use the coating with self-lubricating function in the sliding process of aluminum alloy at high temperature.

The comparison of average friction coefficient between coated and uncoated friction pairs at different temperatures is shown in Fig. 6. The average friction coefficient of different die surface treatments increased first and then decreased with the increase of temperature. The coatings all showed good lubricating effect at 300 °C. Among them, the average friction coefficient of boriding treated samples is the smallest (0.647) at 300 °C. Form the above results, it can be seen that the friction property of WC-a-C:H coating at 300 °C is more stable than that of other coatings.

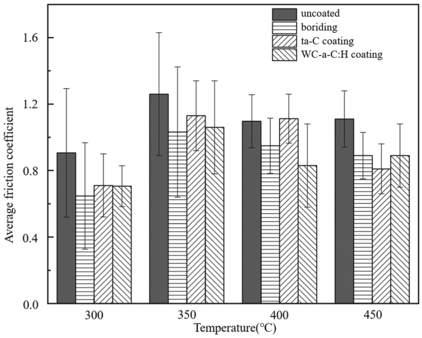

Fig. 6. Comparison of average friction coefficient of different temperature and friction pair coating.

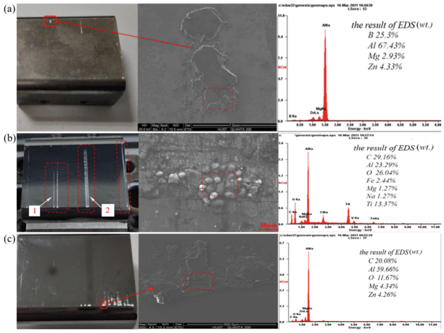

Fig. 7. SEM and EDS results of surface adhesion of friction pair under different surface treatments at 450 °C: (a) boriding treatment, (b) ta-C coating, (c) WC-a-C:H coating.

3.2 Adhesion Phenomenon and Mechanism Analysis Under Different Surface Treatments

It can be seen from Fig. 7(a) that the adhesion on the surface of the boriding friction pair is massive, showing a layered structure and a smooth and flat upper surface, indicating that the adhesion points have increased in the continuous sliding process and are flattened under the pressure, which explains the fluctuation of the friction coefficient during the experiment and the subsequent decrease. The main elements of the surface adhesion are Al and B, with the mass fraction of 67.43% and 25.3% respectively. The high mass fraction of Al indicates that the aluminum alloy sheet exists material transfer phenomenon during the sliding process. And B should come from the surface FeB layer of boriding, indicating that the surface FeB layer may be broken at 450 °C, and the broken surface FeB may play a positive role in improving the friction process.

The SEM and EDS results in Fig. 7(b) are at position 2. From SEM photos, it can be seen that there are obvious smearing traces on the surface of the friction pair, and it has the characteristics of scale like cracking and spalling. EDS analysis results show that there are more C, Al, O elements and a small amount of Fe elements in this region, which indicates that oxidation also occurs in the process of friction. For DLC coating, the transformation from sp^3 structure to sp^2 structure will occur at elevated temperature. The coating will be graphitized (generally non hydrogen DLC > 450 °C, hydrogen DLC > 350 °C), resulting in coating failure. In this experiment, because the sheet temperature is close to the critical temperature of ta-C coating, during the continuous sliding process, the coating will undergo graphitization transformation. At the same time, the coating will peel off due to the large difference of thermal expansion coefficient of each part of the coating and the effect of internal stress.

Figure 7(c) is the SEM photos and EDS analysis of the surface adhesion of WC-a-C:H coating friction pair at 450 °C. It can be seen from Fig. 7(c) that the morphology of adhesion substance is similar to that of adhesion of boriding friction pair. The upper surface is smooth and flat, but the volume is larger, indicating that more serious accumulation during sliding process. The results of EDS analysis show that the main elements in the adhesion substance are C, Al and O, which is similar to the analysis results of ta-C coating. Just like ta-C coating, it is the graphitization transformation at high temperature that leads to sharp fluctuations in the friction process.

4 Conclusions

In this paper, the influence of die coating on friction behavior of 7075 aluminum alloy in hot stamping process is studied through plate sliding friction experiment simulation. The main conclusions are as follows:

(1) The coatings all showed good lubricating effect at 300 °C. The average friction coefficient of the surface treated specimens is significantly lower than that of the untreated specimens, and remains in a lower range (0.6–0.75).
(2) The average friction coefficient of boriding samples at 300 °C is the lowest, and the anti-adhesion ability is the best. At 300 °C, the boriding sample has the lowest average friction coefficient (0.647), and the FeB layer on the die surface may play a positive role in the friction process. On the contrary, the other two conditions failed due to graphitization during elevated temperature friction.
(3) The friction coefficient curve of WC-a-C:H coating fluctuates least at 300 °C, and its friction performance is more stable than other coatings.

Acknowledgments. This research work was financially supported by the National Major Science Technology Project of China (grant no. 2018zx04023001).

References

1. Y. Dong, D. Formosa, J. Fernandhaoez, X. Li, G. Fuentes, K. Zoltan, H. Dong, Y. Qin, T. A. Dean and J. Lin, Development of low-friction and wear-resistant surfaces for low-cost Al hot stamping tools, *MATEC Web of Conferences* **21**, 5009 (2015).
2. Y. C. Zhu, K. Yukimura, C. X. Ding and P. Y. Zhang, Tribological properties of nanostructured and conventional WC-Co coatings deposited by plasma spraying, *Thin Solid Films* **388**, 277 (2001).

3. T. Horiuchi, S. Yoshihara and I. Yu, Dry deep drawability of A5052 aluminum alloy sheet with DLC-coating, *Wear* **286-287**, 79 (2012).
4. Y. C. Dong, K. L. Zheng, J. Fernandez, X. Y. Li and H. S. Dong, Experimental investigations on hot forming of AA6082 using advanced plasma nitrocarburised and CAPVD WC: C coated tools, *Journal of Materials Processing Technology* **240**, 190 (2017).
5. K. L. Zheng, Y. C. Dong, H. S. Dong, J. Fernandez and T. A. Dean, Investigation of the lubrication performance using WC: C coated tool surfaces for hot stamping AA6082, *Procedia Engineering* **207**, 711 (2017).
6. Y. C. Dong, K. L. Zheng, G. Fuentes and H. S. Dong, Low adhesion effect of novel duplex NC/WC:C coatings against ductile materials at elevated temperatures, *Materials Letters* **220**, 32 (2018).
7. H. Torres, T. Caykara, H. Rojacz, B. Prakash, and M. Rodriguez Ripoll, The tribology of Ag/MoS2-based self-lubricating laser claddings for high temperature forming of aluminum alloys, *Wear* **442–443**, 203110 (2020).